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people resources solutions

Online CD Performance Monitoring and Automatic Alignment Correction

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May 1-4

PaperCon 2011

Northern Kentucky Convention Center

RETHINK PAPER:

Lean and Green

Outlines

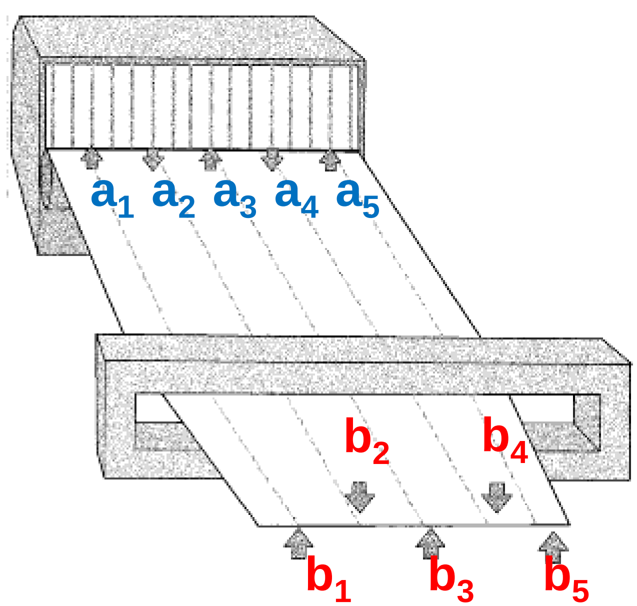
- Introduction to CD Alignment
  - *The traditional alignment identification approach*
  - *The new solution: adaptive alignment*
- Performance Monitoring
- Closed-loop Alignment Identification
- Mill Trial Results
- Conclusions

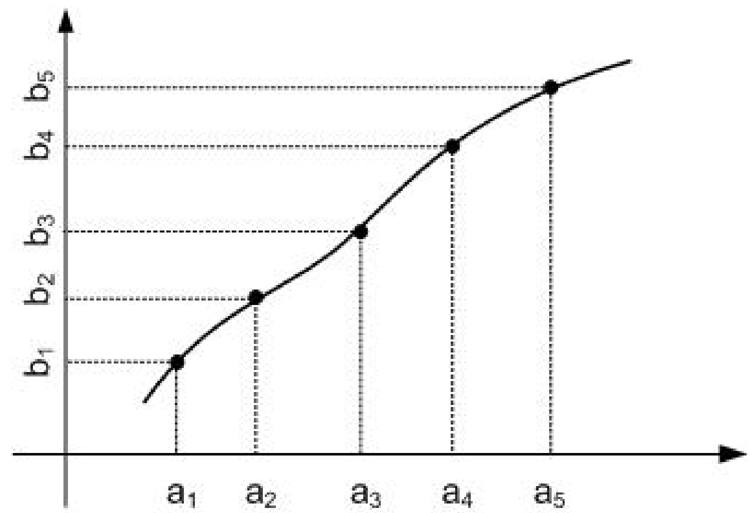
Introduction to CD Alignment

- CD Alignment Definition

  Alignment specifies the spatial relationship between the CD actuators and paper quality measurements. It is a critical model parameter of a CD process

- Traditional CD Alignment Identification Approach

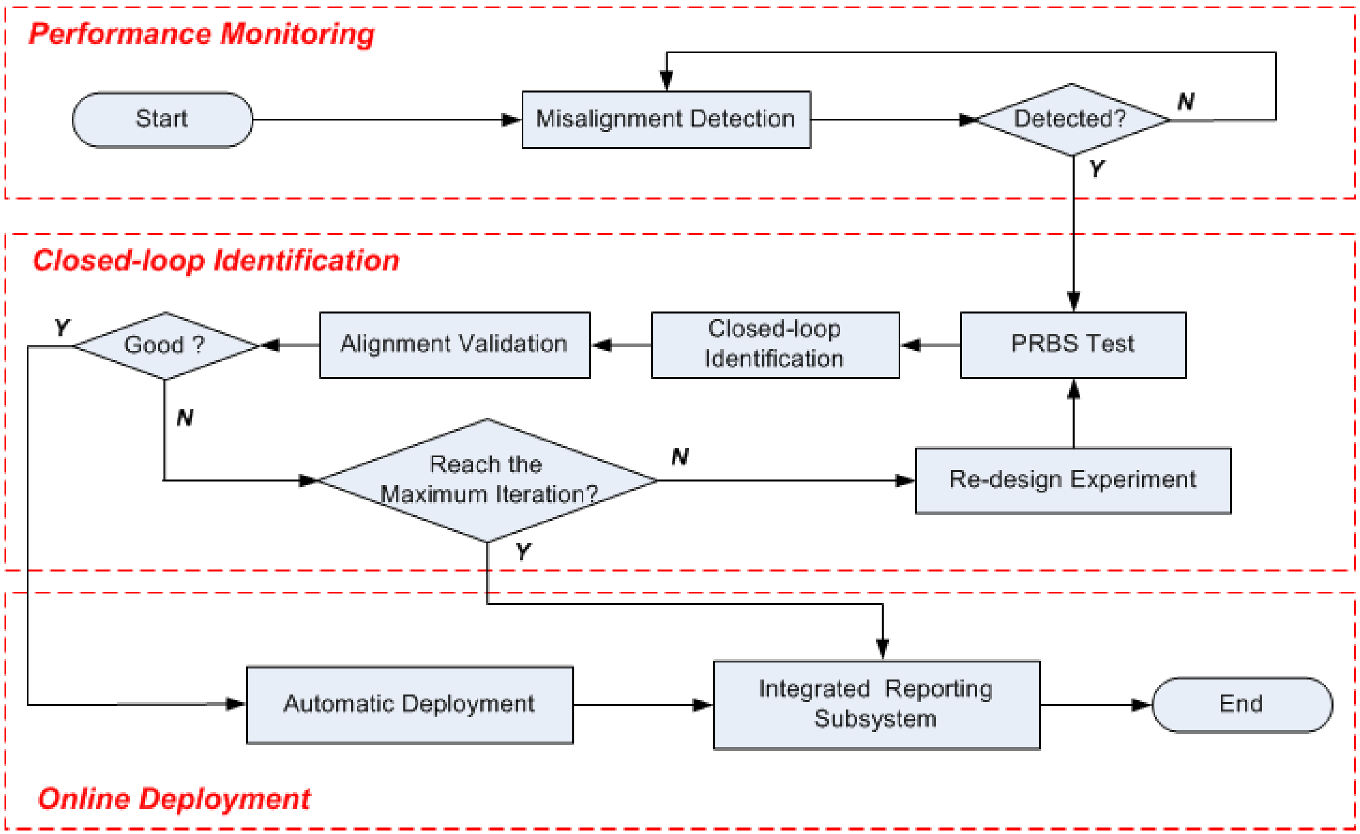




Linear or Nonlinear

The New Solution: Adaptive Alignment

- Overview of the adaptive alignment

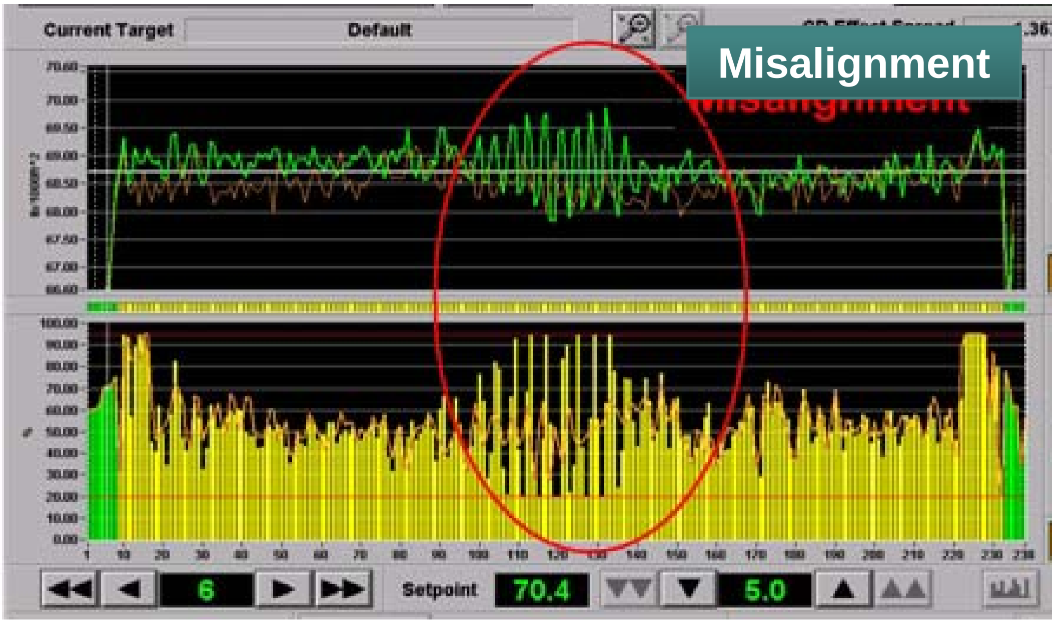


- ***Fully automated; no user intervention is required!***

Performance Monitoring

- Actuator Picketing

Actuator picketing is a well-known symptom of misalignment and is used to trigger the closed-loop identification.



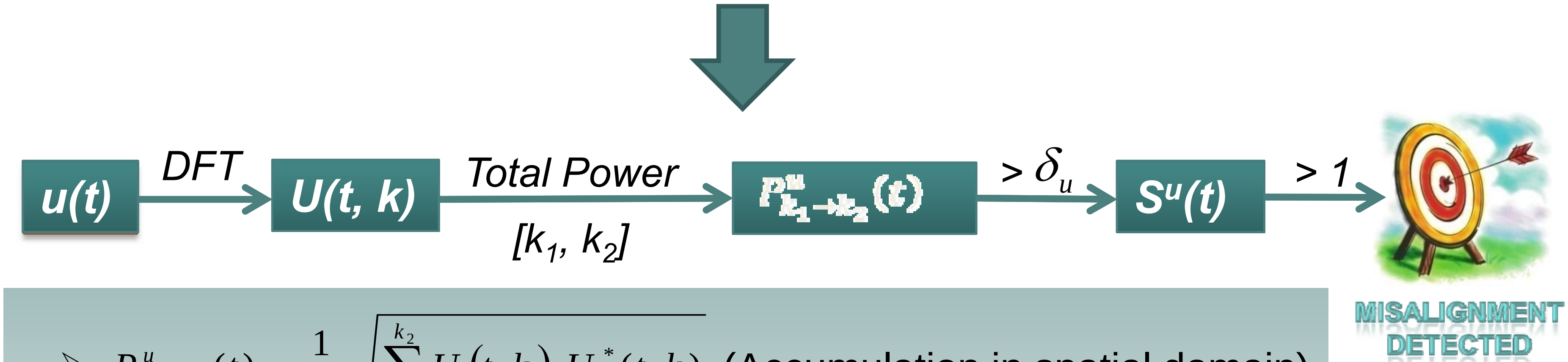
How to mathematically evaluate the actuator picketing?

True process data before using adaptive alignment

Misalignment Detection

- Revised CUSUM algorithm

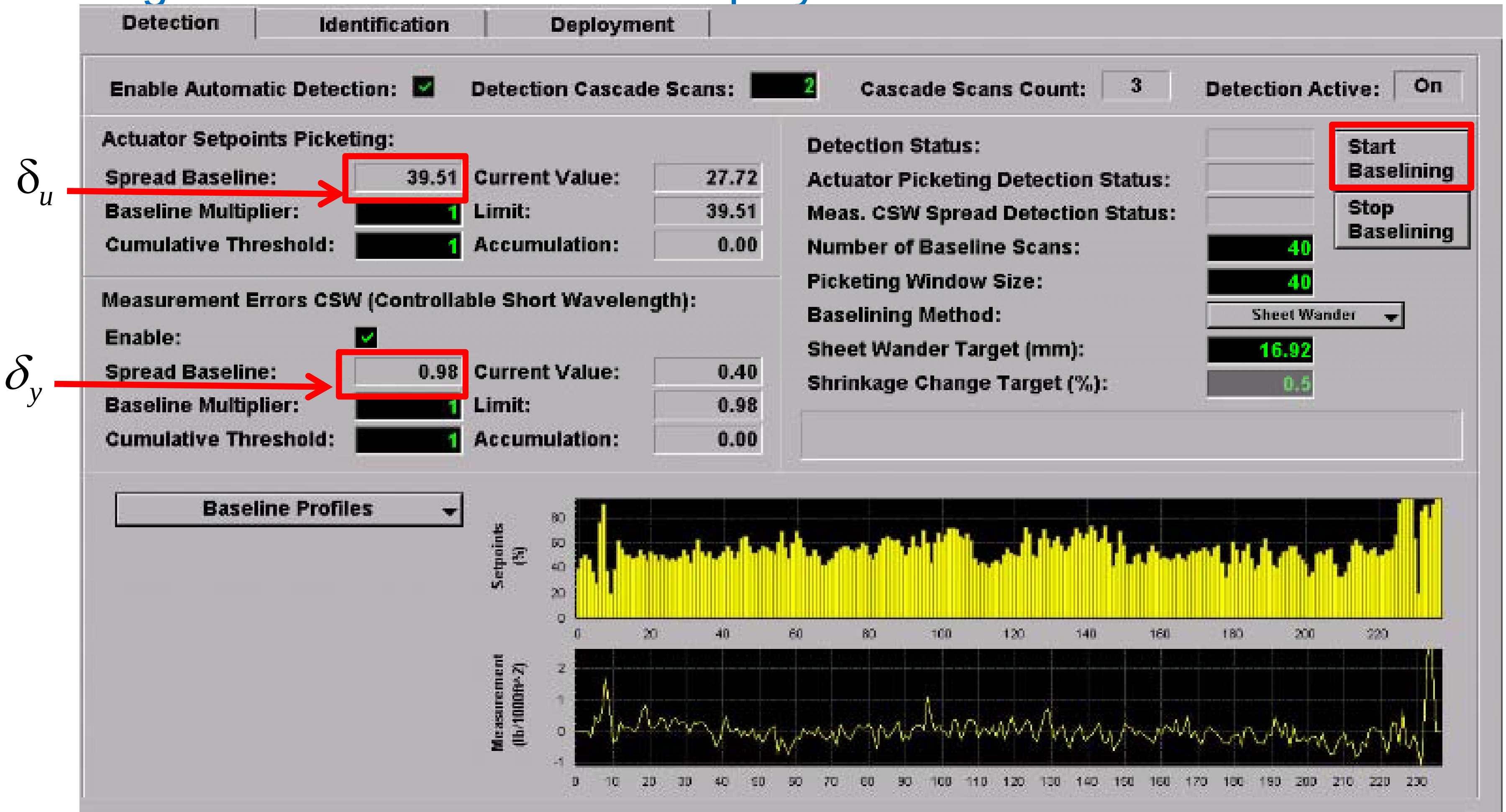
  Key Idea: the onset of actuator picketing results in the growth of the high frequency components in the actuator power spectrum.



- $P^u_{k_1 \to k_2}(t) = \frac{1}{N}\sqrt{\sum_{k=k_1}^{k_2} U(t,k) \cdot U^*(t,k)}$ (Accumulation in spatial domain)
- $S^u(t+1) = S^u(t) + (\frac{P^u_{k_1 \to k_2}(t)}{\delta_u} - 1)$ (Accumulation in time domain)
- δ_u is the performance index and is determined by the **Performance Baselining** operation (One button click).

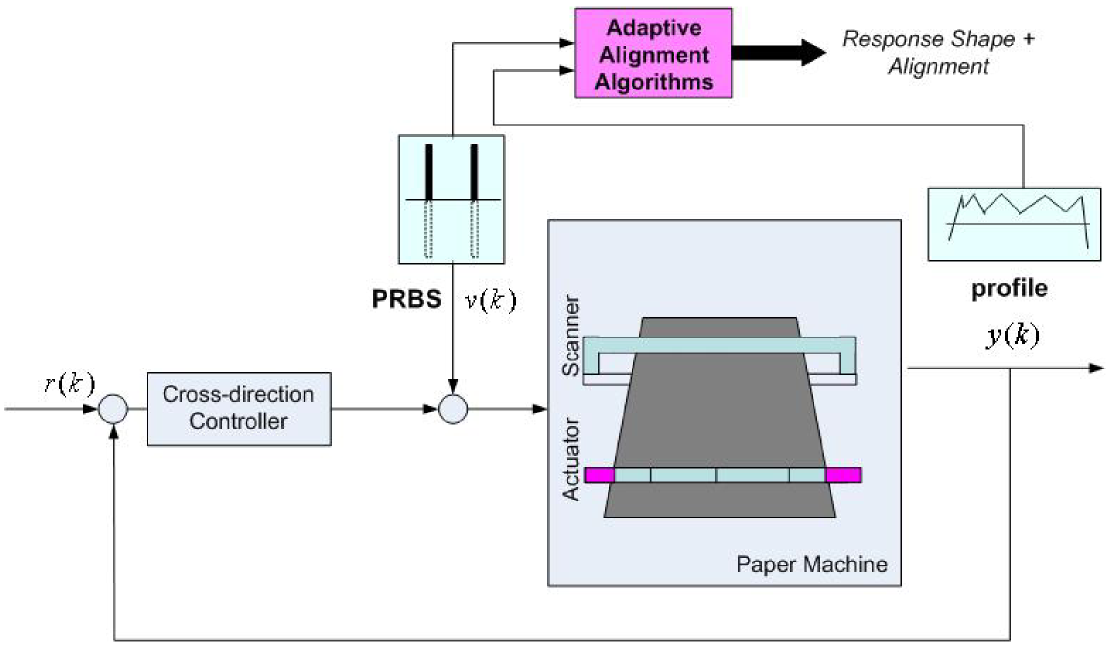
Misalignment Detection

- Misalignment Detection User Display

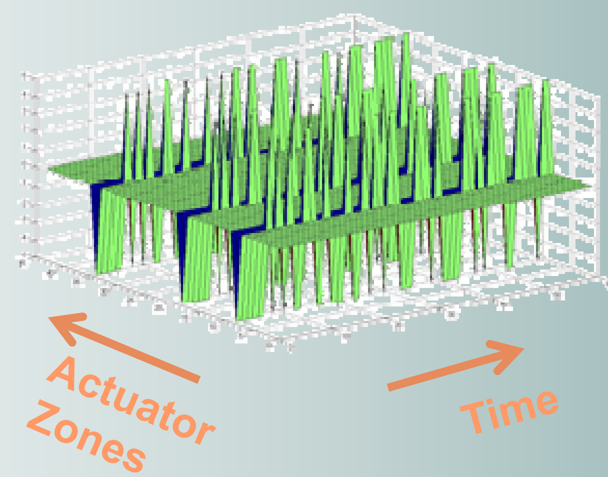


Closed-loop CD Alignment Identification

- Closed-loop PRBS Dithering Tests



- v(k) is a PRBS dithering signal



- Open and closed-loop
- Automatic PRBS experiment design (location + pattern)
- Linear and nonlinear shrinkage

Closed-loop CD Alignment Identification

- Closed-loop ID Algorithm (Two step identification)
  - Step 1: Spatial response shape identification ($\hat{g}_u$)

$$\hat{g}_u = \frac{R_{y\phi}(T_d + i)}{h_{T_d+i} R_\phi^0} \quad (i = 0,1,\cdots,T_d - 1)$$

  - Step 2: Alignment identification (θ_M^0)

$$\theta_M^0 = \arg\min_{\theta_M} \| g_u(\theta_M) - \hat{g}_u \|$$

***Key Features*:**
1. Extracts open loop responses from closed-loop experiment data
2. Provides adaptive PRBS experiments

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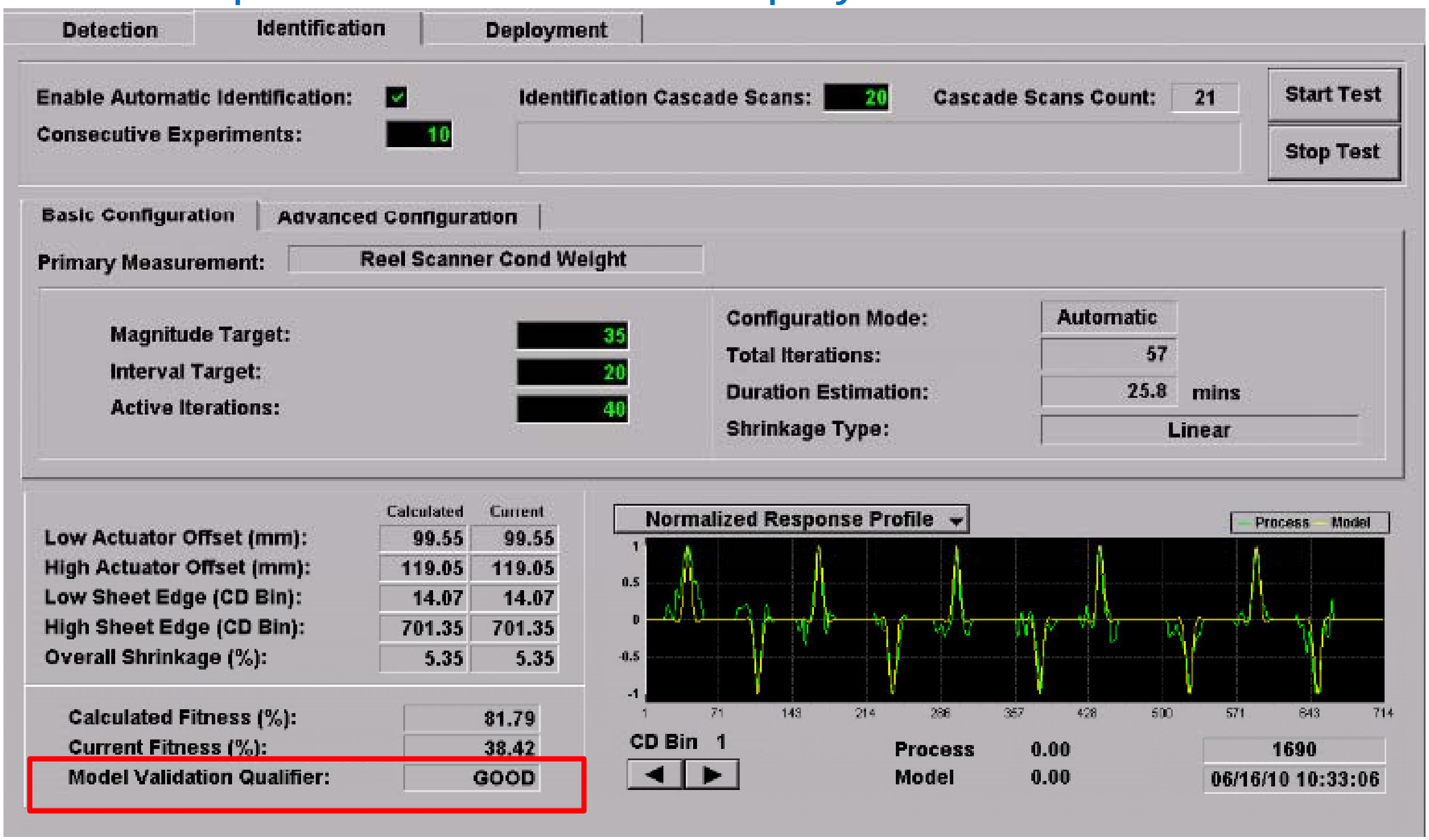
Closed-loop CD Alignment Identification

- Closed-loop Identification User Display



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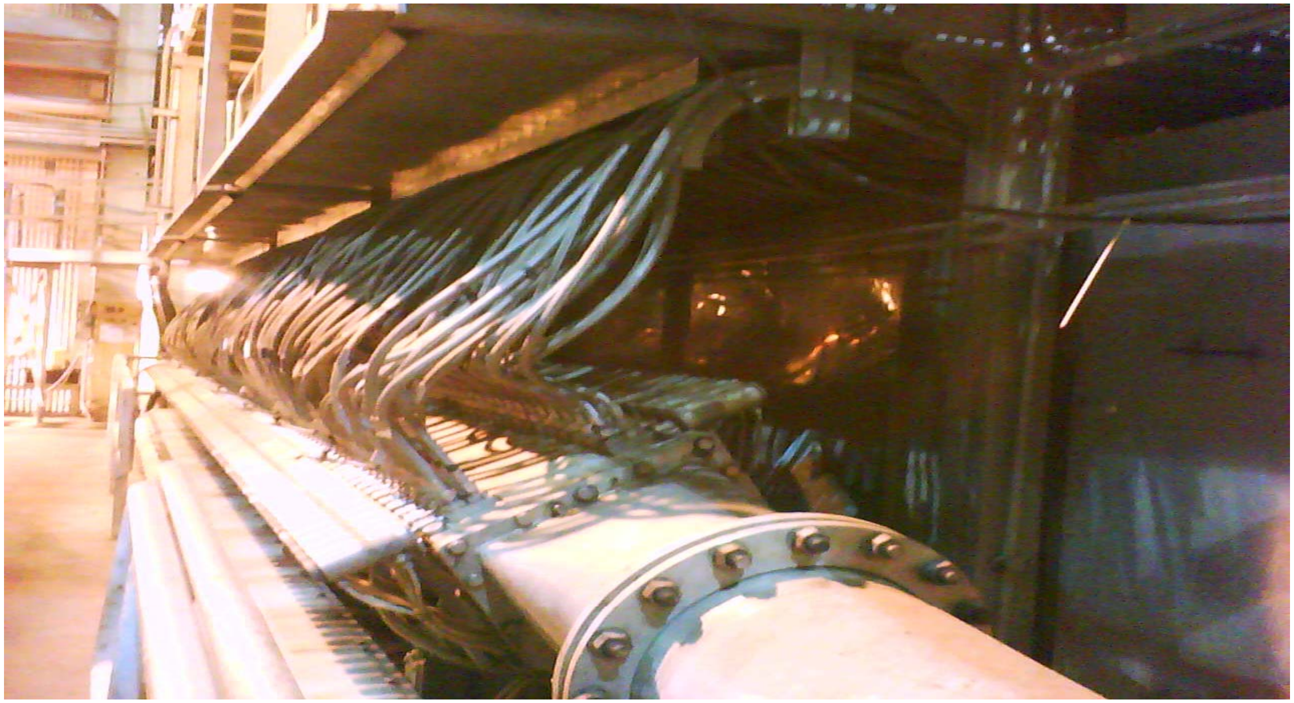
Mill Trial Results

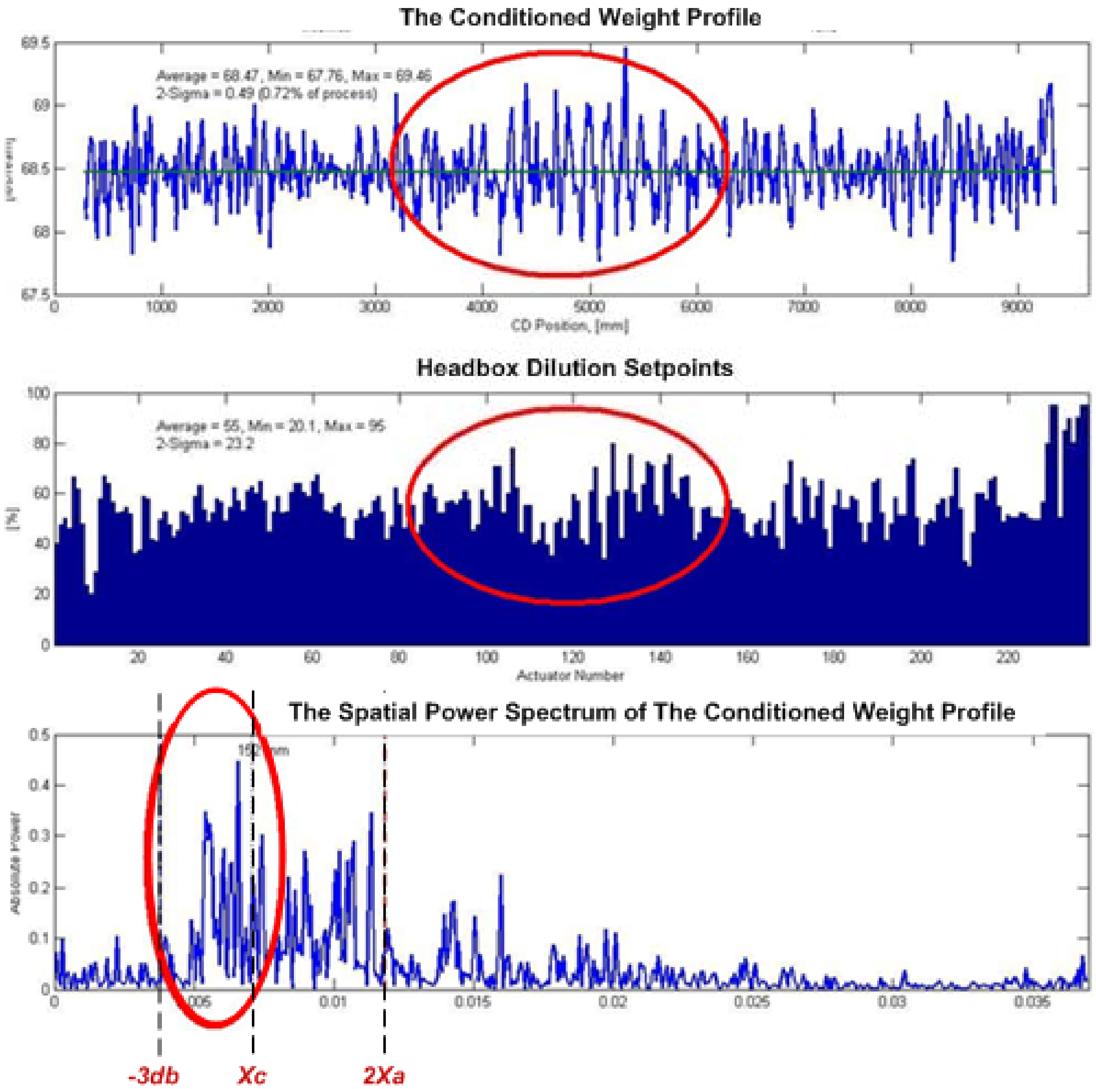
- The Trial on A Linerboard Machine



- ***The test was applied to the headbox dilution CD actuator***
- ***The Number of Zones = 238, Actuator Spacing = 42.16mm (1.7 inch)***
- ***Dilution setpoint profiles and Conditioned Weight profiles were monitored***

Mill Trial Results

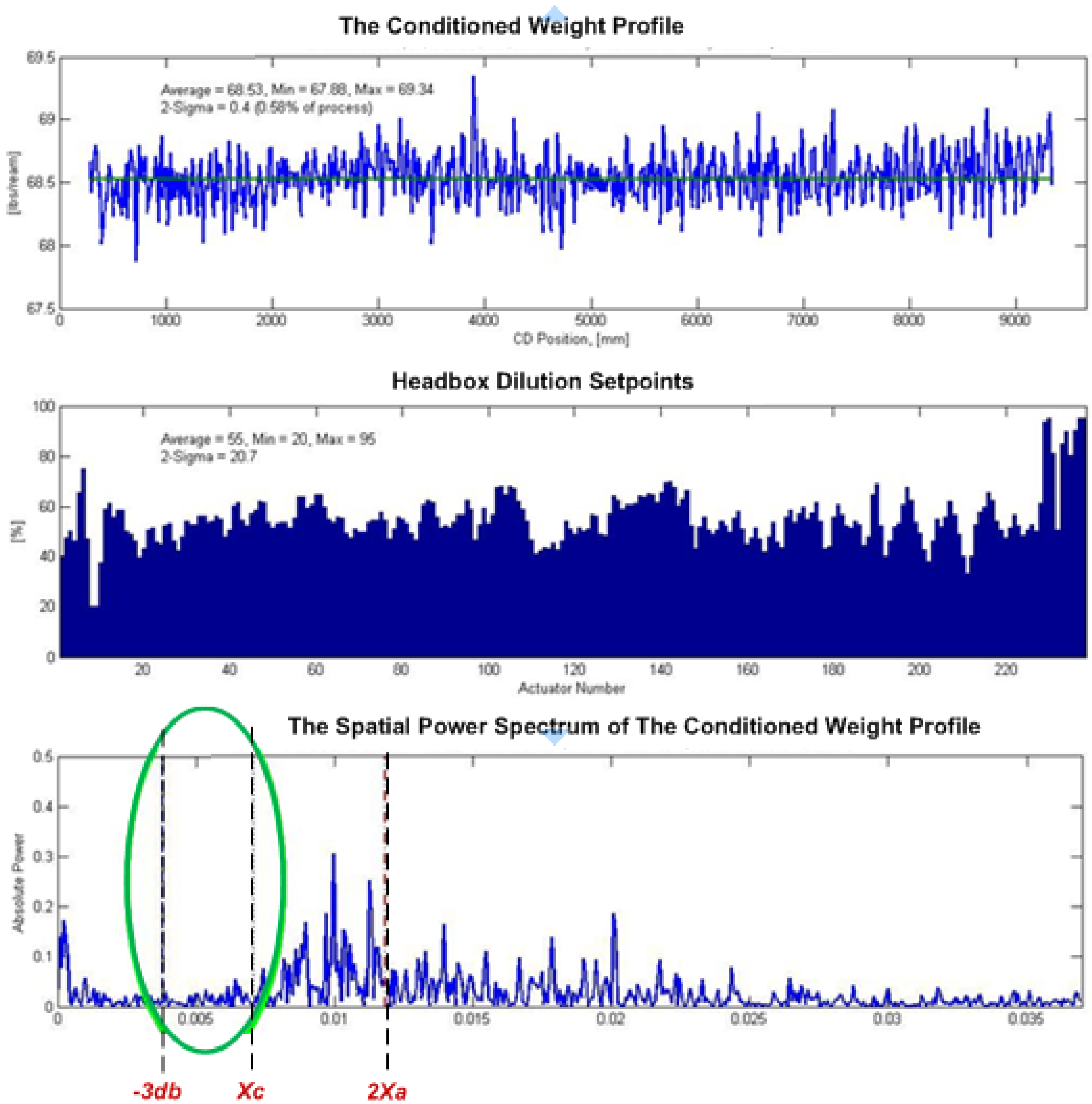
- Misalignment was detected, and the profiles below illustrate the process situation just before the closed-loop identification started



- *The typical actuator picketing pattern can be vaguely observed*
- *Misalignment causes the power accumulation in the spatial frequency band [-3db, Xc]*
- *Severe actuator picketing is prevented*

Mill Trial Results

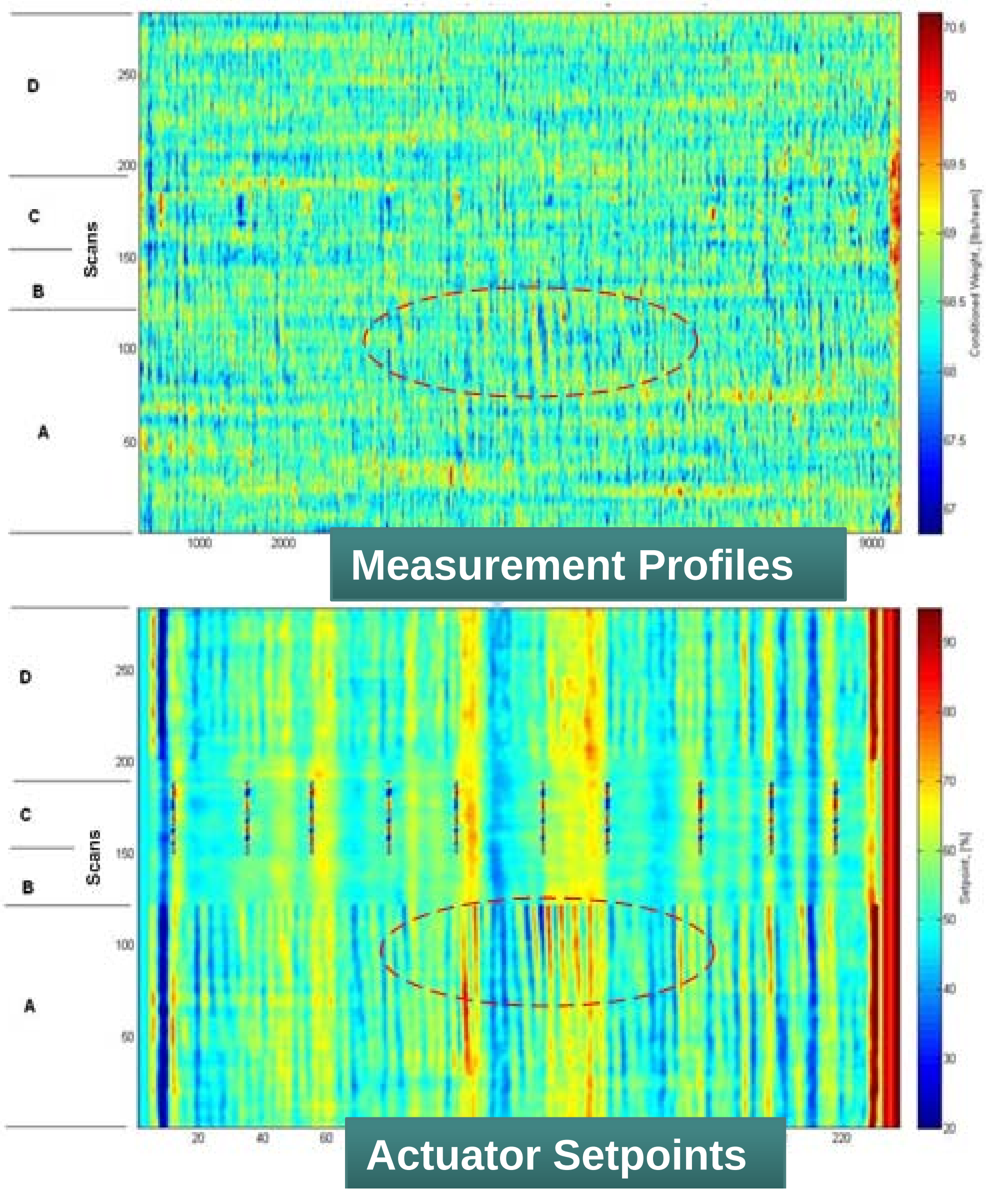
- The profiles after correcting the CD alignment in closed-loop



- *The profile variability between -3db to Xc was effectively attenuated*
- *2σ was reduced by 18.4% from 2.39 gsm to 1.95 gsm*
- *The CD process was operated at the "optimal" condition.*

Mill Trial Results

- The color map of logged profiles during the adaptive alignment test



- In *Region A*, misalignment was monitored and detected;
- In *Region B*, the feedback controller was automatically retuned to stabilize the process
- In *Region C*, a PRBS dithering test was implemented
- In *Region D*, the new alignment was deployed and CD controller used more aggressive tuning parameters automatically.

- ***The 2σ was reduced by 18.4% from 2.39 gsm to 1.95 gsm***

Conclusions

- The adaptive alignment provides CD performance monitoring, identification, and deployment in closed-loop;
- The entire process is fully adaptive and does not require user intervention;
- The performance monitoring algorithm can detect the misalignment long before any signs become visible to the operator
- The identification algorithms provide an adaptive PRBS dithering tests and the reliable alignment model validation;
- The algorithm can be extended to full spatial model identification;
- The adaptive alignment can prevent 18% - 24% of increase in product variability due to poor CD alignment.